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Long Life Nickel Electrodes for Nickel-Hydrogen Cells

Fiber Substrates Nickel Electrodes

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July 2000

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1. Executive Summary

Samples of nickel fiber mat electrodes were investigated over a wide range of fiber diameters, electrode thickness, porosity and active material loading levels. Thickness' were 0.040, 0.060 and 0.080 inches for the plaque; fiber diameters were primarily 2, 4, and 8 μ and porosity was 85, 90, and 95%. Capacities of 3.5 inch diameter electrodes were determined in the flooded condition with both 26% and 31% potassium hydroxide solution. These capacity tests indicated that the highest capacities per unit weight were obtained at the 90% porosity level with a 4 μ diameter fiber plaque. It appeared that the thinner electrodes had somewhat better performance, consistent with sintered electrode history.

Limited testing with two-positive-electrode boiler plate cells was also carried out. Considerable difficulty with constructing the cells was encountered with short circuits the major problem. Nevertheless, four cells were tested. The cell with 95% porosity electrodes failed during conditioning cycling due to high voltage during charge. Discharge showed that this cell had lost nearly all of its capacity. The other three cells after 20 conditioning cycles showed capacities consistent with the flooded capacities of the electrodes.

Positive electrodes made from fiber substrates may well show a weight advantage of standard sintered electrodes, but need considerably more work to prove this statement. A major problem to be investigated is the lower strength of the substrate compared to standard sintered electrodes. Problems with welding of leads were significant and implications that the electrodes would expand more than sintered electrodes need to be investigated. Loading levels were lower than had been expected based on sintered electrode experiences and the lower loading led to lower capacity values. However, lower loading causes less expansion and contraction during cycling so that stress on the substrate is reduced.

2. Introduction

The previous interim report submitted in March 1994 described the final results of the Destructive Physical Analysis (M-25) of the 48 Ah flight-type cells from Task M-17. These cells were subsequently delivered to Naval Surface Warfare Center, Crane for their cycle life test in April 1994.

The objective of "Improved Utilization of Nickel Electrodes" task (M-28) was to improve active material utilization of nickel electrodes with lightweight substrate material by using alternate activation and substrate passivation procedures. Nickel electrodes having high theoretical specific energy were prepared using lightweight substrate which was made of nickel fiber, nickel powder, and optional cobalt powder. However, these electrodes showed low utilization of the active material indicating that improvement of utilization was needed. In May 1994 an additional 0.030" thick plaque made of 8-μ nickel fibers was impregnated at a reduced impregnation current. Loading level was rather low (1.3 g/cc void). Eight flooded electrolyte cells were fabricated using nickel electrodes selected from this and previous impregnation runs.

Measurements of electrode capacities and active material utilization of 3.5" diameter nickel electrodes made of nickel fiber mat substrates in 26% and 31% KOH electrolytes were completed in June of 1994. All the test electrodes were low loaded (1.2 to 1.3 g/cc void) electrodes from preliminary impregnation runs. Results for 0.080" thick 2m diameter nickel fiber substrates are summarized in Table 1. These electrodes showed very high utilization of the active material, i.e., 108% and 112% in 26% and 31% KOH electrolytes, respectively. Results for 0.030" thick 8-μ diameter nickel fiber substrates are summarized in Table 2. These electrodes showed rather low utilization of the active material, i.e., 91% and 95% for lot 1 and 79% and 82% for lot 2 in 26% and 31% KOH electrolytes, respectively. However, the results were not conclusive since the effects of thickness and loading levels still needed to be evaluated.

Table 1 - Electrode capacities and active material utilization of 3.5" diameter nickel electrodes made of 0.080" thick 2-μ diameter nickel fiber mat substrates.

Electrode ID	Average Capacity, Ah in 31% KOH	Average Capacity, Ah in 26% KOH	Average Utilization, % in 31% KOH	Average Utilization, % in 26% KOH
#14	2.36	2.33	119.7	118.2
#15	2.45	2.39	111.0	108.3
#20	2.53	2.45	110.7	106.9
#21	2.60	2.52	113.4	109.9
#22	2.56	2.48	113.0	109.5
#23	2.61	2.44	110.0	102.8
#24	2.62	2.54	109.5	106.2
#25	2.67	2.57	108.2	104.3
#26	2.66	2.57	110.4	106.6
Average	2.56	2.47	111.8	108.1

Table 2 - Electrode capacities and active material utilizations of 3.5" diameter nickel electrodes made of 0.030" thick 8μ diameter nickel fiber mat substrates.

Lot No.	Electrode ID	Average Capacity, Ah in 31% KOH	Average Capacity, Ah in 26% KOH	Average Utilization, % in 31% KOH	Average Utilization, % in 26% KOH
Lot 1	B1	0.96	0.93	94.6	91.4
Lot 1	B5	1.27	1.22	96.0	92.0
Lot 1	B4	1.29	1.23	93.6	88.8
Average		1.17	1.12	94.7	90.7
Lot 2	C1	1.14	1.10	80.9	77.9
Lot 2	C3	1.06	1.02	84.7	81.6
Lot 2	C4	1.10	1.06	79.5	76.7
Average		1.10	1.06	81.7	78.7

The objective of "Fiber Substrate Nickel Electrodes" task (M-33) was to improve active material utilization by using lightweight substrates which are made of fine nickel fibers (2 to 16 mm). These substrates have much more uniform pore size distribution than the substrates used in the previous task. Nickel electrodes using these substrates were expected to show much improved utilization over those in the previous task.

This final report will focus on task (M-33).

3. Electrode Fabrication

3.1 Plaque Requirements

Plaques of various fiber sizes, porosities, and thickness were fabricated at Memtec America Corporation. Details of the plaque matrix for the plaque that was fabricated at Memtec America is shown in Table 3 below.

Plaques of 2μ diameter fiber size were fabricated at Ribbon Technology Corporation (Ribtec). Initial samples of these plaques were received from Ribtec late in February 1995. One group of the plaques had 93.2% porosity and the other had 86.2% porosity. The balance of the plaques of 2μ diameter nickel fiber size were expected to be delivered in the beginning of June.

Three sheets of 26-mil thick and approximately 525 cm^2 in area sample plaques made of 8μ diameter fibers were received from Memtec America Corporation in March 1995.

In May 1995, we received pre-production samples of plaques of the following types from Memtec America Corporation for our inspection and decision for production:

4μ diameter nickel fiber / 94% porous / 0.062 inch thick
4μ diameter nickel fiber / 94% porous / 0.042 inch thick
8μ diameter nickel fiber / 90% porous / 0.062 inch thick
8μ diameter nickel fiber / 94% porous / 0.042 inch thick

Table 3 - Details of the plaque matrix for the plaque fabricated at Memtec

Plaque ID	Thickness	Fiber diameter	Porosity
A4-85	0.040"	4μ	85%
A4-90	0.040"	4μ	90%
A4-95	0.040"	4μ	95%
B4-85	0.060"	4μ	85%
B4-90	0.060"	4μ	90%
B4-95	0.060"	4μ	95%
C4-85	0.080"	4μ	85%
C4-90	0.080"	4μ	90%
C4-95	0.080"	4μ	95%
A8-85	0.040"	8μ	85%
A8-90	0.040"	8μ	90%
A8-95	0.040"	8μ	95%
B8-85	0.060"	8μ	85%
B8-90	0.060"	8μ	90%
B8-95	0.060"	8μ	95%
C8-85	0.080"	8μ	85%
C8-90	0.080"	8μ	90%
C8-95	0.080"	8μ	95%
B12-90	0.060"	12μ	90%
B16-90	0.060"	16μ	90%

All samples appeared satisfactory without any apparent defects on visual inspection and had uniform texture on microscopic inspection. We asked Memtec America Corporation to go ahead with their production plan with the plaques.

In June 1995 we received 32 sheets of 150 cm^2 size (4.6 inch x 5 inch) plaques of 4μ diameter nickel fiber / 92.4% porous / 0.060 inch thick. In July 1995, we received 6 sheets (12 cm x 38 cm; 4.8 inch x 15 inch) each of four different plaques of 4μ and 8μ diameter fiber size from Memtec and 5 sheets (12 cm x 38 cm; 9.8 inch x 9.8 inch) each of two different plaques of 2μ diameter fiber size from Ribtec. Their design variables are shown in Table 4.

We received additional plaques of B8-85 and C8-90 in September 1995 and we received all of the 2-micron fiber plaques B2-95 and B2-90 from Ribtec as well as partial quantities of six different kinds of plaques out of total 20 from Memtec (types A4-95, A4-85, A8-90, B8-85, B8-90, and C8-90) in December 1995.

Table 4 - Plaques design variables

Plaque ID	Fiber size μm	Av. thckn. inch	Average por. %	Manufacturer
A4-95	4	0.037	92.7	Memtec
A4-85	4	0.030	82.0	Memtec
B8-90	8	0.055	90.7	Memtec
A8-85	8	0.033	88.0	Memtec
B2-95	2	0.061	94.3	Ribtec
B2-90	2	0.074	90.0	Ribtec

A total of approximately 20 ft^2 of substrate (A4-85, A4-90, A4-95, and B4-95 types) were received from Memtec in April 1996. Plaque of 8μ fiber size were delivered from Memtec in August 1996. However, we had to ship them back for rework since we found that the plaques overall were inadequately sintered causing weak mechanical strength. Memtec sintered them further to achieve adequate strength.

Delivery of additional plaques from Memtec was delayed significantly due to production schedule problems and rejection of a batch of their 4-micron nickel fiber from plaque production due to contamination with iron. In fact, the overall project was delayed by approximately 15 months from the original plan due to cumulative delays of plaque delivery from Memtec by more than 24 months. On October 30, 1996 we received a shipment of raw plaques, which included all but one type (B8-95) of previously missing 8μ diameter fiber plaques.

3.2 Plaque Impregnation

In February 1995, plaques of 2μ diameter fiber size which were fabricated at Ribtec were coated with cobalt oxide for passivation. Preliminary loading experiments were carried out on these plaques by applying various current densities ranging from 42 to 110 mA/cm^2 in double to triple loading steps. Results showed high surface loading of the active material and rather low loading in the pores as shown in Table 5 which show the results after scrubbing off most of the surface loading mechanically.

Table 5 - Loading data from preliminary loading experiments of 2μ diameter fiber plaques. Loading values are averages of three 3.5-inch diameter electrodes.

Plq. No	Impreg.-1 i*	Impreg.-1 t**	Impreg.-2 i*	Impreg.-2 t**	Impreg.-3 i*	Impreg.-3 t**	Thckn cm	Porosity %	Load level g/cc void	Theo. cap Ah/el	Sp. Cap. mAh/g
A1	110	150	42	300			0.15	93.5	0.86	1.69	161.90
A2	63	300	42	300			0.15	93.2	1.26	2.45	184.53
A4	110	150	63	92	42	300	0.15	93.5	1.15	2.26	181.93
A6	110	150	63	92	42	300	0.15	92.8	1.02	1.98	166.67
B2	63	300	63	160			0.15	86.2	1.19	2.14	124.60
B4	63	300	63	160			0.15	86.2	1.20	2.14	125.17

* in mA/cm2; ** in min

Impregnation experiments at reduced current densities (down to 16 mA/cm^2) were carried out in March 1995 on the 2μ diameter fiber plaques from Ribtec Corporation. Measurements of electrode capacity of electrodes prepared earlier using 86% and 93% plaques (B2 and A2, respectively) showed high active material utilization values of 111 and 103%, respectively, as shown in Table 6. Despite its low loading level (1.2 g/cc-void), the A2 electrode had encouragingly high specific electrode capacity of 187 mAh/g.

Table 6 - Active material utilization and theoretical and actual specific electrode capacity of 2μ diameter fiber plaques from Ribtec.

Plaque No.	Thickness cm	Porosity %	Load level g/cc void	Theoretical mAh/g	Actual mAh/g	Utilization %
A2	0.15	93	1.20	182	187	103
B2	0.15	86	1.18	125	138	111

In May 1995, one of 2μ diameter fiber plaques (A3) from Ribtec Corporation was impregnated at 15.6 mA/cm^2 for 10 h followed by additional impregnation 11.1 mA/cm^2 for 6 h. At this reduced current, surface loading which was a problem at a high current density was not apparent indicating that a low current impregnation is desirable for this type of plaque. The impregnation data are shown in Table 7. Despite relatively low loading level theoretical specific capacity of the electrode is encouragingly high (av. 191 mAh/g). A loading level of 1.65 g/cc-void was achieved with a 2μ diameter nickel fiber / 85% porous / 0.060 inch thick plaque by impregnation at the current density of 15.2 A/cm^2. Sample plaques of 8μ diameter fiber size which were received in March 1995 were coated with cobalt oxide for passivation. Weight gain by this coating was 5.3 ± 0.6 % grams.

Table 7 - Loading data and theoretical specific electrode capacity from preliminary loading experiments of 2μ diameter fiber plaques from Ribtec.

Electrode No	Plaque thckn, cm	Electrode thkn, cm	Porosity (plq) %	Porosity (ele) %	Load level g/cc void	Theo. Sp. Cap. mAh/g
A3-1	0.150	0.157	93.0	93.3	1.52	194.9
A3-2	0.150	0.159	93.0	93.4	1.44	191.2
A3-3	0.150	0.153	93.0	93.1	1.38	188.4

After receiving the 32 sheets of 150 cm^2 size (4.6 inch X 5 inch) plaques of 4μ diameter nickel fiber / 92.4% porous / 0.060 inch thick in June 1995. Individual plaque sheets were weighed and coined for one Hughes standard 3 1/2-inch diameter electrode per plaque. Four each of these coined plaques were attached together to make a 600 cm^2 size (10 inch X 9.2 inch) plaque sheet for impregnation. The attachment was done by welding them at three corners of each of the 150 cm^2 -size plaques using a 3/4 inch x 1 inch nickel sheet on each side of the plaque. These 600 cm^2 -size plaques were coated with cobalt oxide according the original work plan. The plaque was impregnated at 22 mA/ cm^2 for 12 hours. The loaded plaques appeared uniform and showed only very slight surface loading which was scrubbed off easily. The average active material loading level was 1.5 g/cc void. The loading corresponded to a theoretical specific capacity of 176 mAh/g of electrode.

One of the Memtec plaques made of 8μ diameter fibers was impregnated with active material for 6 hours at a current density of 32 mA/cm^2. Resulting plaque showed a high loading level up to 1.9 g/cc-void based on original plaque thickness and theoretical specific electrode capacity up to 185 mAh/g of the electrode as shown in Table 8, although the actual loading level after plaque thickness expansion (21%) was 1.53 g/cc-void.

Table 8 - Loading data and theoretical specific electrode capacity from preliminary loading experiments of 8μ diameter fiber plaques from Memtec.

Electr. No	Impregn. mA/cm^2	hrs	Plaque thckn. cm	Electr. thckn. cm	Porosity A (plq) %	Porosity B (ele) %	Load level A g/cc void	Load level B g/cc void	Theo. Sp. Cap. mAh/g
Mem01 -1	31.6	6	0.066	0.080	90.09	91.82	1.38	1.71	177.91
Mem01 -2	31.6	6	0.066	0.080	90.09	91.82	1.53	1.90	184.84

An additional impregnation was carried out on A-95 plaque in November 1995. Three additional impregnation runs were carried out in December 1995. Cumulative impregnation data are summarized in Table 9.

Plaque passivation by cobalt oxide coating was carried out for several types of plaque in January 1996. An impregnation run was carried out on a B8-90 type. We were able to impregnate only two plaques (B8-90 and B2-90 types) in February 1996 due to the impregnation tank schedule problem caused by other urgent flight cell programs. We planned to re-impregnate both plaques since they had much lower weight pick-up than expected.

Table 9 - Cumulative impregnation data.

Plq. ID	Thickn.	Porosity	Impregnation		Loading	Av. Util.	Measured	Theoret.
	mm	%	mA/cm2	t, h	av.g/cc	%	mAh/g	mAh/g
A4-95-1	0.97	92.9	22.0	13	1.62	103.6	202.8	195.8
A4-95-2	0.92	92.6	22.0	13	1.38	106.1	189.4	178.5
A4-95-5	0.89	92.5	25.0	13	1.23			173.4
A4-95-6	0.88	92.3	25.0	13	1.34			180.6
A4-85-x	0.76	81.7	TBI					
B8-85-x	1.42	87.7						
B8-90-3	1.39	90.0	25.0	15	1.19			168.6
B8-90-4	1.41	91.4	25.0	15	1.10			166.6
B8-90-5	1.61	91.9	TBI					
B8-90-6	1.38	89.5	TBI					
A8-90-x	0.83	88.1	TBI					
C8-90-x	1.78	89.1						
B2-95-2	1.65	94.6	22.1	13	1.39	82.4	167.3	203.0
B2-95-3	1.47	94.1	18.3	17	1.20	95.0	189.5	199.5
B2-95-4	1.47	94.2	25.0	15	1.08			183.8
B2-95-6	1.68	94.8	TBI					
B2-95-7	1.80	95.4	TBI					
B2-90-1	1.80	89.9	25.0	15	0.92			139.2
B2-90-2	1.78	90.0	TBI					
B2-90-3	1.98	90.0	TBI					

We impregnated three plaques (B8-90, A8-90, and B2-90 types) in March 1996. Impregnation parameters and active material loading data are shown in Table 10. Flow rate of bath circulation had a great effect on the loading efficiency as shown in Table 10 . When the flow rate was reduced to 2gal/min from previous 5.5gal/m the impregnation time was reduced drastically.

Table 10 - Impregnation data

Plq ID	Thckn cm	Porosity %	i, mA/cm2	time, h	Flow rate GPM	av.g/cc	Theor. mAh/g
B8-90-5	0.161	91.9	35.0	21	5.5	1.34	180.6
B8-90-6	0.138	89.5	35.0	21	5.5	1.34	175.5
A8-90-1	0.085	87.5	35.0	4	2.0	1.34	173.4
A8-90-2	0.084	87.4	35.0	4	2.0	1.41	177.1
B2-90-2	0.178	90.0	20.0	21	5.5	1.29	163.0

In April 1996 We impregnated two plaques (A4-85 types) using two different values of bath circulation rates (1 and 2 gal/min, respectively). Electrodes were ready to be punched from the plaques. Lack of available impregnation bath schedule time, which was caused by other urgent flight cell programs was expected to be a continuing problem until late 1996. Therefore we arranged a subcontract with Eagle-Picher Industries (EPI), Colorado Springs, CO, for the impregnation of future plaques. We planned to utilize available impregnation time at EPI in the time period of June to August, 1996. The first impregnation run of a lot of several plaques was scheduled in early June (6/3-4/96). Plaque preparation which includes coining, tab-welding, and the cobalt treatment, was completed in April 1996 at Hughes facility for plaque received from Memtec. Most of these plaques were shipped to EPI for impregnation.

Two impregnation runs of sixteen plaques (C4-85, C4-90, C4-95, B4-85 types) in each run were carried out at EPI on July 29, 1996. Loading levels based on original plaque thickness varied from 0.9 to 1.7 g/cc-void, while loading level based on electrode thickness was lower than these values due to plaque expansion during the impregnation. Theoretical specific capacity of electrodes from 85%-porosity plaques was approximately

140 mAh/g at best, while that of 90%-porosity plaques was up to 170 mAh/g and that of 95%-porosity plaques was up to 226 mAh/g. Although the electrodes from 95%-porosity plaques showed very high specific capacity, weak mechanical strength might be a problem which needs to be solved, since it was difficult to attach tabs to some of the electrodes.

41 plaques of 8μ diameter fiber and 11 plaques of 4μ diameter fiber were shipped to EPI for impregnation on December 2, 1996. These plaques included all but one type (B8-95) of previously missing types, i.e., B4-95, C4-95, A8-85, A8-95, B8-85, C8-85, C8-90, and C8-95. Thirty seven plaques were impregnated during month of December (12/12/96).

3.3 Formation of Impregnated Plaques

Four electrodes (electrode ID: Mm-1 to Mm-4) were fabricated in July 1995 using 93% porous, 0.060-inch thick, 4μ fiber plaques which were impregnated at 22 mA/cm^2 for 12 hours. Their nominal loading level was 1.62 g/cc void based on nominal thickness and 1.31 g/cc void based on electrode thickness. Their average utilization of active material was 95% and measured specific capacity was 182 mAh/g of electrode weight.

In July 1995, three of A4-95 type impregnation plaques (750 cm^2-size) were made by attaching two pieces together followed by coining for six 3.5-inch diameter electrodes per plaque and coating with cobalt oxide. One of these plaques was impregnated at 22 mA/cm^2 for 13 hours.

Four impregnations (A4-95-1&2, A4-95-1&2, B2-95-2, and B2-95-3) were carried out in August 1995. Data for these impregnations and some of earlier ones (B4-95-Mmx) are summarized in Table 11. The data include plaque thickness, porosity, impregnation current densities, resulting loading levels, and results of electrochemical utilization measurements. It is evident that, for 4μ fiber plaques (A4-95 and B4-95 series), those plaques impregnated at 22 mA/cm^2 show substantially higher utilization than those impregnated at 18 mA/cm^2. One of those (1.1 mm thick) impregnated at 22 mA/cm^2 (A4-95-1&2) showed full utilization while the other B4-95-Mm1 (1.8 μ thick) showed an average utilization value of 94.7%. Such a trend was not clear with 2μ fiber plaques (B2-95 series) possibly due to a statistically insufficient number of data points.

In September 1995, A4-85, A8-90, B8-90, and B2-90 plaques were assembled, processed, coined and impregnated with cobalt.

Nine electrodes from earlier impregnation runs were being tested in May 1996 for their initial characteristics in a flooded electrolyte cell containing 26% and 31% KOH electrolytes sequentially. In June 1996 we began punching electrodes and measuring weight pick-up and thickness for determination of loading level and plaque expansion during impregnation. Loading data from earlier runs are summarized in Table 12. Electrode capacity and active material utilization of selected electrodes from various earlier impregnation lots were measured as shown in Table 13. High loading of active material for the actual plaque porosity (based on electrode thickness) above 1.3-1.4 g/cc void was difficult to achieve, because the fiber-base substrate is much softer than the conventional sinter substrate and it expands easily as the active material was loaded. All electrodes tested (Table 13) had active material loading level in this range. Measured values of the active material utilization varied from 90 to 126% in 26% KOH and 93 to 126% in 31% KOH electrolyte. Measured capacity density which is the most important measure of usefulness was up to 208 mAh/g in both 26 and 31% KOH electrolytes.

Electrodes were punched out of the plaques from EPI Run No. 5 impregnation in December 1996. Active material pick-up values were much lower than our target values for many plaques. Those plaques which showed a reasonable active material pick-up were punched out for electrodes.

Table 11 - Summary of cumulative plaque and electrode data for large size plaques.

Plq ID	Thckn	Porosity	Impregnation		Load level	Theo.	Utilization	Measured
	mm	%	mA/cm2	hrs	g/cc void	mAh/g	%	mAh/g
A4-95-1	*1.16*	*94.0*	*22.0*	*13*	*1.60*	*199.9*	*110.8*	*220.2*
A4-95-1	*1.17*	*94.1*	*22.0*	*13*	*1.54*	*198.4*		
A4-95-1	*0.98*	*93.0*	*22.0*	*13*	*1.73*	*193.4*	*96.4*	*185.3*
A4-95-2	*1.08*	*93.7*	*22.0*	*13*	*1.34*	*184.5*		
A4-95-2	*1.09*	*93.7*	*22.0*	*13*	*1.36*	*185.9*	*107.2*	*189.2*
A4-95-2	*1.06*	*93.5*	*22.0*	*13*	*1.43*	*187.1*	*105.0*	*189.5*
Average	1.1	93.7	22.0	13.0	1.50	191.5	104.9	196.1
B4-95-Mm1	*1.90*	*93.7*	*22.0*	*12*	*1.28*	*191.0*	*94.0*	*179.5*
B4-95-Mm1	*1.70*	*93.4*	*22.0*	*12*	*1.39*	*193.7*	*102.7*	*198.9*
B4-95-Mm1	*1.90*	*93.8*	*22.0*	*12*	*1.26*	*191.5*	*83.9*	*160.6*
B4-95-Mm1	*1.84*	*93.6*	*22.0*	*12*	*1.30*	*191.8*	*98.3*	*188.5*
Average	1.8	93.6	22.0	12.0	1.3	192.0	94.7	181.9
A4-95-3	*1.04*	*93.3*	*18.4*	*17*	*1.67*	*194.3*	*74.5*	*144.5*
A4-95-3	*0.95*	*92.7*	*18.4*	*17*	*1.82*	*193.7*		
A4-95-3	*0.94*	*92.6*	*18.4*	*17*	*1.68*	*187.8*		
A4-95-4	*1.00*	*93.2*	*18.4*	*17*	*1.69*	*193.8*		
A4-95-4	*1.04*	*93.4*	*18.4*	*17*	*1.76*	*199.1*	*53.6*	*105.9*
A4-95-4	*1.09*	*93.7*	*18.4*	*17*	*1.63*	*197.5*		
Average	1.0	93.1	18.4	17.0	1.71	194.4	64.1	125.2
B4-95-Mm2	*1.73*	*93.8*	*18.3*	*16*	*1.41*	*198.3*	*68.5*	*135.9*
B4-95-Mm2	*1.81*	*94.1*	*18.3*	*16*	*1.27*	*196.0*	*62.7*	*122.9*
B4-95-Mm2	*1.78*	*93.8*	*18.3*	*16*	*1.12*	*184.3*	*61.7*	*113.7*
B4-95-Mm2	*1.78*	*93.8*	*18.3*	*16*	*1.36*	*196.6*	*57.2*	*112.5*
Average	1.8	93.9	18.3	16.0	1.3	193.8	62.5	121.3
B2-95-2	*1.91*	*95.4*	*22.1*	*13*	*1.36*	*203.7*	*92.4*	*186.6*
B2-95-2	*1.90*	*95.3*	*22.1*	*13*	*1.41*	*205.4*	*72.4*	*148.0*
B2-95-2	*1.84*	*95.2*	*22.1*	*13*	*1.35*	*200.8*		
B2-95-2	*1.76*	*95.0*	*22.1*	*13*	*1.43*	*201.3*	*67.4*	*132.9*
Average	1.9	95.2	22.1	13.0	1.4	202.8	77.4	155.8
B2-95-3	*1.98*	*95.6*	*18.3*	*17*	*1.23*	*202.6*	*71.7*	*136.2*
B2-95-3	*1.96*	*95.6*	*18.3*	*17*	*1.21*	*200.6*	*96.9*	*189.4*
B2-95-3	*1.96*	*95.6*	*18.3*	*17*	*1.18*	*199.2*		
B2-95-3	*2.00*	*95.7*	*18.3*	*17*	*1.18*	*200.7*	*93.1*	*189.5*
Average	2.0	95.6	18.3	17.0	1.2	200.8	87.2	171.7

Table 12 - Data from EPI Lot 7/22/96

TABLE 12 - DATA EPI LOT 7/22/96											
Plq ID	Thickn	Porosity	Impreg	Impregnation			Electrode	Pick-up	LL plq	Theo. cap	Theo
	cm	%	Date	I, A	mA/cm2	t, hrs	wt,g	g	g/cc void	Ah/el	mAh/g
A4-85-16	0.096		6/3/96	20.2	30	4	13.83	5.41	1.46	1.56	113.07
	0.096		6/3/96	20.2	30	4	14.16	5.74	1.55	1.66	117.13
	0.096		6/3/96	20.2	30	4	13.09	4.67	1.26	1.35	103.10
A4-85-17	0.094		6/3/96	20.2	30	4	12.48	4.11	1.14	1.19	95.26
	0.094		6/3/96	20.2	30	4	13.52	5.15	1.42	1.49	110.16
	0.094		6/3/96	20.2	30	4	12.65	4.29	1.18	1.24	97.92
A4-85-18	0.088		6/3/96	20.2	30	4	13.60	5.09	1.54	1.47	108.33
	0.088		6/3/96	20.2	30	4	15.17	6.67	2.01	1.93	127.05
	0.088		6/3/96	20.2	30	4	13.62	5.11	1.54	1.48	108.59
A4-85-19	0.085		6/3/96	20.2	30	4	13.21	4.63	1.47	1.34	101.28
	0.085		6/3/96	20.2	30	4	14.09	5.51	1.75	1.59	113.08
	0.085		6/3/96	20.2	30	4	13.04	4.45	1.41	1.29	98.79
Av									**1.48**	**1.47**	**107.80**
A4-85-5	0.079	79.6	6/14/96	14.3	20	6.33	14.23	6.66	2.23	1.93	135.33
	0.079	79.6	6/14/96	14.3	20	6.33	14.27	6.70	2.24	1.94	135.72
A4-85-6	0.077	82.6	6/14/96	14.3	20	6.33	12.56	6.31	2.08	1.82	145.21
	0.077	82.6	6/14/96	14.3	20	6.33	12.58	6.33	2.09	1.83	145.42
A4-85-20	0.098		6/14/96	14.3	20	6.33	12.84	4.51	1.18	1.30	101.59
	0.098		6/14/96	14.3	20	6.33	14.99	6.66	1.75	1.93	128.52
	0.098		6/14/96	14.3	20	6.33	13.69	5.36	1.41	1.55	113.29
A4-85-21	0.095		6/14/96	14.3	20	6.33	12.75	4.22	1.16	1.22	95.58
	0.095		6/14/96	14.3	20	6.33	15.05	6.51	1.79	1.88	125.13
	0.095		6/14/96	14.3	20	6.33	13.61	5.07	1.39	1.47	107.78
A4-85-22	0.097		6/14/96	14.3	20	6.33	10.58	5.42	1.31	1.57	148.00
	0.097		6/14/96	14.3	20	6.33	10.93	5.76	1.40	1.67	152.49
A4-85-23	0.096		6/14/96	14.3	20	6.33	13.40	4.99	1.35	1.44	107.72
	0.096		6/14/96	14.3	20	6.33	14.42	6.02	1.62	1.74	120.63
	0.096		6/14/96	14.3	20	6.33	12.85	4.45	1.20	1.29	100.02
A4-85-24	0.095		6/14/96	14.3	20	6.33	12.99	4.65	1.27	1.35	103.60
	0.095		6/14/96	14.3	20	6.33	14.58	6.25	1.70	1.81	123.92
	0.095		6/14/96	14.3	20	6.33	13.16	4.82	1.31	1.39	105.98
A4-85-25	0.103		6/14/96	14.3	20	6.33	14.08	5.29	1.32	1.53	108.58
	0.103		6/14/96	14.3	20	6.33	14.53	5.74	1.43	1.66	114.20
	0.103		6/14/96	14.3	20	6.33	13.91	5.11	1.28	1.48	106.31
Av									**1.55**	**1.61**	**120.20**
A4-90-1	0.083		6/3/96	20.2	30	4	9.27	3.91	1.14	1.13	121.83
A4-90-1	0.083		6/3/96	20.2	30	4	11.16	5.80	1.69	1.68	150.15
A4-90-1	0.083		6/3/96	20.2	30	4	10.72	5.35	1.56	1.55	144.40
A4-90-2	0.092		6/3/96	20.2	30	4	10.73	5.54	1.43	1.60	149.23
A4-90-2	0.092		6/3/96	20.2	30	4	10.78	5.59	1.44	1.62	149.95
A4-90-2	0.092		6/3/96	20.2	30	4	10.66	5.47	1.41	1.58	148.34
A4-90-3	0.091		6/3/96	20.2	30	4	11.04	5.79	1.51	1.67	151.55
A4-90-3	0.091		6/3/96	20.2	30	4	11.61	6.36	1.66	1.84	158.30
A4-90-3	0.091		6/3/96	20.2	30	4	11.10	5.85	1.53	1.69	152.31
A4-90-4	0.089		6/3/96	20.2	30	4	9.98	4.77	1.28	1.38	138.13
A4-90-4	0.089		6/3/96	20.2	30	4	10.51	5.30	1.42	1.53	145.73

TABLE 12 Continued - DATA EPI LOT 7/22/96											
Plq ID	Thickn	Porosity	Impreg	Impregnation			Electrode	Pick-up	LL plq	Theo. cap	Theo
	cm	%	Date	I, A	mA/cm2	t, hrs	wt,g	g	g/cc void	Ah/el	mAh/g
A4-90-4	0.089		6/3/96	20.2	30	4	10.39	5.18	1.39	1.50	144.19
A4-90-5	0.089		6/3/96	20.2	30	4	10.66	5.43	1.46	1.57	147.19
A4-90-5	0.089		6/3/96	20.2	30	4	11.03	5.79	1.55	1.68	151.91
A4-90-5	0.089		6/3/96	20.2	30	4	10.97	5.73	1.54	1.66	151.16
A4-90-6	0.091		6/3/96	20.2	30	4	10.17	4.99	1.30	1.44	141.94
A4-90-6	0.091		6/3/96	20.2	30	4	10.03	4.85	1.27	1.40	139.85
A4-90-6	0.091		6/3/96	20.2	30	4	9.84	4.67	1.22	1.35	137.02
Av									**1.43**	**1.55**	**145.70**
A4-90-7	0.090		6/14/96	14.3	20	6.33	9.83	4.68	1.24	1.35	137.72
A4-90-7	0.090		6/14/96	14.3	20	6.33	9.94	4.79	1.27	1.39	139.45
A4-90-7	0.090		6/14/96	14.3	20	6.33	10.00	4.86	1.28	1.40	140.38
A4-90-8	0.090		6/14/96	14.3	20	6.33	10.73	5.38	1.43	1.56	145.03
A4-90-8	0.090		6/14/96	14.3	20	6.33	10.87	5.52	1.47	1.60	146.90
A4-90-8	0.090		6/14/96	14.3	20	6.33	10.01	4.67	1.24	1.35	134.76
A4-90-9	0.092		6/14/96	14.3	20	6.33	10.54	5.20	1.35	1.50	142.78
A4-90-9	0.092		6/14/96	14.3	20	6.33	11.31	5.98	1.55	1.73	152.77
A4-90-9	0.092		6/14/96	14.3	20	6.33	10.81	5.48	1.42	1.58	146.45
A4-90-10	0.090		6/14/96	14.3	20	6.33	9.72	4.45	1.18	1.29	132.53
A4-90-10	0.090		6/14/96	14.3	20	6.33	10.68	5.42	1.44	1.57	146.62
A4-90-10	0.090		6/14/96	14.3	20	6.33	10.40	5.14	1.36	1.49	142.83
A4-90-11	0.089		6/14/96	14.3	20	6.33	9.86	4.77	1.28	1.38	139.92
A4-90-11	0.089		6/14/96	14.3	20	6.33	10.67	5.58	1.49	1.61	151.19
A4-90-11	0.089		6/14/96	14.3	20	6.33	10.06	4.96	1.33	1.44	142.75
A4-90-12	0.088		6/14/96	14.3	20	6.33	10.26	5.15	1.39	1.49	145.11
A4-90-12	0.088		6/14/96	14.3	20	6.33	10.40	5.29	1.43	1.53	147.07
A4-90-12	0.088		6/14/96	14.3	20	6.33	9.61	4.50	1.22	1.30	135.39
A4-90-13	0.092		6/14/96	14.3	20	6.33	10.92	5.63	1.46	1.63	149.24
A4-90-13	0.092		6/14/96	14.3	20	6.33	11.55	6.27	1.62	1.81	156.90
A4-90-13	0.092		6/14/96	14.3	20	6.33	10.55	5.26	1.36	1.52	144.33
A4-90-14	0.089		6/14/96	14.3	20	6.33	11.53	6.30	1.69	1.82	158.04
A4-90-14	0.089		6/14/96	14.3	20	6.33	11.70	6.47	1.74	1.87	159.90
A4-90-14	0.089		6/14/96	14.3	20	6.33	10.58	5.36	1.44	1.55	146.33
Av									**1.40**	**1.53**	**145.20**
A4-95-13	0.108	93.4	6/3/96	20.2	30	4	7.87	4.56	0.94	1.32	167.26
A4-95-13	0.108	93.4	6/3/96	20.2	30	4	8.36	5.04	1.04	1.46	174.36
A4-95-13	0.108	93.4	6/3/96	20.2	30	4	8.56	5.24	1.08	1.52	177.01
A4-95-14	0.100	92.6	6/3/96	20.2	30	4	8.80	5.34	1.20	1.54	175.47
A4-95-14	0.100	92.6	6/3/96	20.2	30	4	9.06	5.61	1.26	1.62	178.81
A4-95-14	0.100	92.6	6/3/96	20.2	30	4	8.81	5.36	1.20	1.55	175.68
Av		**93.01**							**1.12**	**1.50**	**174.80**
A4-95-15	0.107	93.3	6/14/96	14.3	20	6.33	8.05	4.70	0.98	1.36	168.71
A4-95-15	0.107	93.3	6/14/96	14.3	20	6.33	7.64	4.29	0.89	1.24	162.24
A4-95-15	0.107	93.3	6/14/96	14.3	20	6.33	7.05	3.70	0.77	1.07	151.64
A4-95-16	0.107	93.2	6/14/96	14.3	20	6.33	7.39	3.97	0.83	1.15	155.19
A4-95-16	0.107	93.2	6/14/96	14.3	20	6.33	7.62	4.20	0.87	1.21	159.30
A4-95-16	0.107	93.2	6/14/96	14.3	20	6.33	7.49	4.07	0.85	1.18	156.96
Av		**93.23**							**0.86**	**1.20**	**159.00**

TABLE 12 continued - DATA EPI LOT 7/22/96											
Plq ID	Thickn	Porosity	Impreg	Impregnation			Electrode	Pick-up	LL plq	Theo. cap	Theo
	cm	%	Date	I, A	mA/cm2	t, hrs	wt,g	g	g/cc void	Ah/el	mAh/g
A8-90-5	0.081	88.6	6/14/96	14.3	20	6.33	9.08	4.73	1.37	1.37	150.68
A8-90-5	0.081	88.6	6/14/96	14.3	20	6.33	8.33	3.98	1.15	1.15	138.13
A8-90-5	0.081	88.6	6/14/96	14.3	20	6.33	8.35	4.01	1.16	1.16	138.64
A8-90-6	0.080	88.4	6/14/96	14.3	20	6.33	8.12	3.75	1.10	1.08	133.52
A8-90-6	0.080	88.4	6/14/96	14.3	20	6.33	7.90	3.53	1.04	1.02	129.25
A8-90-6	0.080	88.4	6/14/96	14.3	20	6.33	8.30	3.93	1.15	1.13	136.82
Av		**88.47**							**1.16**	**1.15**	**137.80**
B8-85-1	0.141	75.4	6/3/96	27.2	30	4.5	15.00	5.99	1.02	1.73	115.38
B8-85-1	0.141	75.4	6/3/96	27.2	30	4.5	14.56	5.55	0.94	1.60	110.17
B8-85-1	0.141	75.4	6/3/96	27.2	30	4.5	14.15	5.14	0.87	1.48	104.94
B8-85-3	0.142	63.2	6/3/96	27.2	30	4.5	13.64	6.46	1.06	1.87	136.83
B8-85-3	0.142	63.2	6/3/96	27.2	30	4.5	13.65	6.46	1.06	1.87	136.91
B8-85-3	0.142	63.2	6/3/96	27.2	30	4.5	14.09	6.91	1.14	2.00	141.71
B8-85-5	0.142	74.2	6/3/96	27.2	30	4.5	15.89	6.97	1.17	2.01	126.77
B8-85-5	0.142	74.2	6/3/96	27.2	30	4.5	15.72	6.79	1.14	1.96	124.97
B8-85-5	0.142	74.2	6/3/96	27.2	30	4.5	15.94	7.02	1.18	2.03	127.26
B8-85-7	0.144	73.7	6/3/96	27.2	30	4.5	14.97	6.53	1.08	1.89	126.14
B8-85-7	0.144	73.7	6/3/96	27.2	30	4.5	14.80	6.36	1.05	1.84	124.24
B8-85-7	0.144	73.7	6/3/96	27.2	30	4.5	15.37	6.94	1.15	2.00	130.42
Av		**71.63**							**1.07**	**1.86**	**125.50**
B8-90-1	0.132	91.5	6/3/96	27.2	30	4.5	11.17	5.92	1.02	1.71	153.21
B8-90-1	0.132	91.5	6/3/96	27.2	30	4.5	11.17	5.92	1.02	1.71	153.20
B8-90-1	0.132	91.5	6/3/96	27.2	30	4.5	12.05	6.80	1.17	1.97	163.13
B8-90-2	0.128	89.8	6/3/96	27.2	30	4.5	12.30	6.22	1.13	1.80	146.25
B8-90-2	0.128	89.8	6/3/96	27.2	30	4.5	12.83	6.75	1.23	1.95	152.19
B8-90-2	0.128	89.8	6/3/96	27.2	30	4.5	12.27	6.20	1.13	1.79	145.96
Av		**90.65**							**1.12**	**1.82**	**152.30**

Table 13 - Capacity Measurements of Lightweight Electrodes

ELECTRODE	DATE	Weight	Theo.	Rated	Electrode			26% KOH				31% KOH		
ID	COMPLT'D	w/o tab	Cap	Cap	thickness	LL el	LL plq	Av. cap	Practical	Av util		Av. cap	Practical	Av util
		g	Ah	Ah	cm	g/cc void	g/cc void	ah	mAh/g	%		Ah	mAh/g	%
A4-85-1-1	6/4/96	13.584	1.98	2.0	0.119	1.36	2.33	2.23	164.0	112.5		2.23	164.2	112.6
A4-85-1-2	6/4/96	13.711	2.01	2.0	0.125	1.31	2.37	2.22	162.0	110.5		2.22	162.1	110.6
A4-85-1-3	6/4/96	13.365	1.91	2.0	0.119	1.32	2.26	2.19	163.6	114.5		2.19	163.9	114.7
Average									**163.2**	**112.5**			**163.4**	**112.6**
A4-85-3-1	6/4/96	12.567	1.79	2.0	0.115	1.27	2.12	2.25	179.3	125.6		2.26	179.6	125.8
A4-85-3-2	6/4/96	12.507	1.78	2.0	0.116	1.25	2.10	2.24	178.7	125.8		2.24	179.1	126.1
A4-85-3-3	6/4/96	12.457	1.76	2.0	0.108	1.34	2.08	2.24	179.8	127.1		2.24	179.5	126.9
Average									**179.2**	**126.2**			**179.4**	**126.3**
A4-95-6-1	6/4/96	9.945	1.92	2.0	0.1092	1.34	1.69	2.07	208.1	108.1		2.07	207.9	108.0
A4-95-6-3	6/4/96	10.276	2.01	2.0	0.1118	1.37	1.78	2.13	207.5	106.0		2.13	207.6	106.1
Average									**207.8**	**107.1**			**207.8**	**107.0**
A8-90-2-1	6/4/96	12.904	2.30	2.0	0.125	1.45	2.28	2.21	171.1	95.9		2.28	177.0	99.2
A8-90-2-2	6/4/96	12.821	2.28	2.0	0.128	1.40	2.25	2.19	170.9	96.2		2.27	176.9	99.5
A8-90-2-3	6/4/96	12.518	2.19	2.0	0.123	1.40	2.17	2.10	167.5	95.7		2.19	175.1	100.0
Average									**169.9**	**95.9**			**176.3**	**99.6**
B2-90-2-1	6/11/96	21.257	3.56	3.3	0.213	1.28	1.56	3.01	141.7	84.5		3.14	147.7	88.1
B2-90-2-2	6/11/96	21.585	3.40	3.3	0.223	1.25	1.60	3.19	147.8	93.9		3.31	153.3	97.4
B2-90-2-3	6/11/96	21.014	3.43	3.3	0.204	1.31	1.53	3.08	146.7	89.9		3.32	153.4	94.0
Average									**145.4**	**89.5**			**151.5**	**93.2**
B8-90-5-1	6/11/96	17.770	3.19	3.3	0.187	1.32	1.56	3.16	177.8	99.0		3.25	183.0	101.9
B8-90-5-2	6/11/96	18.421	3.38	3.3	0.190	1.37	1.65	3.23	175.2	95.5		3.33	180.6	98.4
B8-90-5-3	6/11/96	17.636	3.15	3.3	0.182	1.34	1.54	3.13	177.6	99.3		3.23	183.4	102.6
B8-90-6-1	6/11/96	18.967	3.35	3.3	0.196	1.32	1.96	3.33	175.6	99.5		3.40	179.3	101.7
B8-90-6-2	6/11/96	19.118	3.39	3.3	0.194	1.36	1.98	3.27	170.9	96.4		3.35	175.1	98.8
B8-90-6-3	6/11/96	18.373	3.17	3.3	0.184	1.34	1.86	3.22	175.5	101.6		3.31	179.9	104.1
Average									**175.4**	**98.5**			**180.2**	**101.2**

4. Electrode Performance Characterization

In February 1997 15 electrodes, rated at 3.0 Ah, were tested. (B4-90, B4-95, B8-85, C8-90, and C8-95). They were soaked in 26% potassium hydroxide solution overnight, then tested for five cycles. In April, the 26% KOH were drained and replaced with 31% KOH. The appropriate capacity tests were then carried out at that concentration of electrolyte.

Nine electrodes from earlier impregnation runs were tested for their initial characteristics in a flooded electrolyte cell containing 26% and 31% KOH electrolytes sequentially.

In September 1996, electrodes from impregnation runs at EPI (C4-85, C4-90, C4-95, B8-90 types) were selected for capacity measurements based on the best loading levels from each group. Flooded electrolyte cells were fabricated and capacity tests were carried out using 26% KOH electrolyte for the first 5 cycles and then 31% KOH electrolyte for the subsequent 3 cycles. Average values of electrode capacity in both electrolytes as well as electrode loading data including porosity and thickness are summarized in Table 14. Active material utilization and measured specific capacity of electrodes were also summarized for both electrolytes. Average values of the measured specific capacity of the electrodes, which is the most interesting property of the electrode, were 213 mAh/g in 26% KOH and 220 mAh/g in 31% KOH for 93%-porosity plaques (A4-95 type), 165 mAh/g in 26% KOH and 173 mAh/g in 31% KOH for 90% porosity plaques (A8-90 type), and 142 mAh/g in 26% KOH and 152 mAh/g in 31% KOH for 87%-porosity plaques (A4-90 type). Although the electrodes from 93%-porosity plaques showed very high specific capacity, weak mechanical strength is as previously noted, a problem which needs to be solved, since we again had difficulty attaching tabs on some of the electrodes. Twenty seven (27) electrodes out of these were selected for capacity measurements in flooded electrolyte cells to determine active material utilization. These included three electrodes each from plaque types, B4-90, B4-95, C4-90, A8-85, A8-95, B8-85, C8-85, C8-90, and C8-95, respectively. The active material loading level for these electrodes were all above 1.30 g/cc of the void volume in the original plaque.

Table 14 - Test data of electrodes impregnated at EPI.

Plq ID	Plaque por.,%	Elect. por.,%	Elect. th. cm	Load level Electr g/cc void	Load level Plq g/cc void	26% KOH CAP Ah	26% KOH Util %	26% KOH Practical mAh/g	31% KOH CAP Ah	31% KOH Util %	31% KOH Practical mAh/g
A4-85-6-1	82.6	89.8	0.132	0.96	1.79	2.00	127	158	2.12	135	169
A4-85-6-2	82.6	90.4	0.139	0.90	1.80	2.00	127	159	2.11	134	168
A4-85-18-1	79.3	82.5	0.104	1.14	1.41	1.61	119	118	1.68	125	124
A4-85-18-2	79.3	84.3	0.116	1.34	1.88	1.80	100	119	1.89	105	125
A4-85-18-3	79.3	84.4	0.117	1.00	1.42	1.71	126	126	1.80	132	132
A4-90-1-1	86.2	90.8	0.125	0.98	1.57	1.61	104	145	1.67	108	150
A4-90-1-2	86.2	90.3	0.118	0.96	1.44	1.55	109	145	1.61	113	150
A4-90-3-1	87.7	92.4	0.147	0.91	1.56	1.52	90	134	1.66	96	143
A4-90-3-2	87.7	92.2	0.144	0.85	1.42	1.54	100	141	1.70	108	153
A4-90-14-1	87.4	91.3	0.129	1.02	1.54	1.62	100	145	1.86	112	161
A4-90-14-2	87.4	90.8	0.122	1.11	1.59	1.61	97	142	1.84	107	157
A4-95-3-1	92.7	93.3	0.104	1.73	1.91	2.40	101	204	2.51	107	217
A4-95-3-2	92.7	92.7	0.095	1.89	1.89	2.51	108	216	2.57	111	223
A4-95-3-3	92.7	92.6	0.094	1.75	1.73	2.37	111	217	2.39	113	221
A4-95-4-1	92.9	93.2	0.100	1.76	1.81	2.44	106	214	2.49	109	220
B8-90-3-1	90.0	92.5	0.185	1.13	1.56	2.79	102	164	2.89	107	172
B8-90-3-2	90.0	92.4	0.183	1.20	1.63	2.80	98	166	2.90	102	173
B8-90-3-3	90.0	92.4	0.183	1.21	1.64	2.81	98	166	2.91	103	173

The electrodes from Run No. 5 were tested in March 1997 for flooded capacity to determine active material utilization. The active material loading level for these electrodes was above 1.30 g/cc of the void volume in the original plaque. The previously used weld schedule needed to be updated for these plaques, especially the 95% porosity plaques. During this period, we developed a successful tab welding schedule using scrap electrodes. Testing of the electrodes (B4-90, B4-95, B8-85, C8-90, and C8-95) from Run No. 5 for flooded capacity was completed in April 1997 and the results tabulated in Table 15.

Table 15 - Summary of Capacity Tests

ELECTRODE ID	THICK CM	ELECTRODE WT, GM	AVERAGE CAP., Ah 26% KOH	AVERAGE CAP, Ah 31% KOH	AVERAGE CAP/WT 31% KOH
B4-95-1-2	0.200	17.840	2.387	2.425	0.14
B4-95-2-2	0.197	16.338	2.361	2.441	0.15
B4-95-2-3	0.205	18.590	2.245	2.308	0.12
B4-90-5-2	0.186	12.606	3.000	3.160	**0.25**
B4-90-5-3	0.226	13.447	2.826	2.995	**0.22**
B4-90-6-1	0.226	13.163	2.997	3.181	**0.24**
B8-85-10-2	0.225	18.636	2.728	2.900	0.16
B8-85-10-3	0.217	17.417	2.530	2.708	0.16
B8-85-14-2	0.205	18.681	2.658	2.855	0.15
C8-90-9-2	0.244	22.042	3.153	3.339	0.15
C8-90-10-1	0.192	18.824	2.658	2.835	0.15
C8-90-11-1	0.216	20.501	2.928	3.129	0.15
C8-95-3-1	0.199	14.891	2.446	2.616	0.18
C8-95-4-3	0.211	14.860	2.416	2.673	0.18
C8-95-5-2	0.169	14.205	2.220	2.358	0.17
I-6 Avg. 20 C	0.0893	12.6		1.680	0.13

The electrodes were compared for their capacity and weight with average data from the same diameter production sintered electrodes. The B4-90- electrodes all had significantly better capacity than any others and much better than the average production electrodes. Since we had carried out the tests at 31% as well as 26% KOH a direct comparison was possible. Since the B4 electrodes were at least twice as thick as the I6 electrode the performance comparison in the starved condition may well be different. Loading levels for the B4 electrodes were low, about 1.2 g/cc of void. The low loading levels while undesirable from a maximum capacity viewpoint might improve utilization, especially in the starved condition.

Additional testing of electrodes (A8-85 and A8-95) for flooded capacity was carried out in May 1997 and the results tabulated in Table 16.

Table 16 - Summary of Electrode Capacity Tests

ELECTRODE ID	THICKNESS CM	WEIGHT GRAMS	AVG. CAPACITY, AH 26%KOH	31%KOH	CAP/WT 31%KOH
A8-85-1-1	0.14	13.31	1.953	2.069	0.16
A8-85-2-2	0.13	13.124	1.853	1.943	0.15
A8-85-2-3	0.131	12.753	1.838	1.926	0.15
A8-95-11-2	0.129	9.278	1.3	1.394	0.15
A8-95-11-3	0.121	9.062	1.138	1.257	0.14
A8-95-16-2	0.151	9.765	1.226	1.35	0.14
I-6 AVG. 20 C	0.0893	12.6	None	1.68	0.13

The electrodes were compared for their capacity and weight with average data from the same diameter production sintered electrodes. All of the electrodes had somewhat better capacity than the average production electrodes. Loading levels for these electrodes were again low by sintered plate standards. However, low loading in this fiber electrode may have an important advantage as well as the obvious disadvantage. The structure of these electrodes is mechanically weaker than sintered electrodes. Therefore if the electrodes were loaded to the same levels as sintered electrodes, the expansion and contraction of the active material during cycling would probably be more damaging to the fiber structure than would occur with the stronger sintered electrodes. The numbers for capacity/weight may be a better measure than loading level of the usefulness of the electrode in making a lighter electrode stack that will also have reasonable life. Calculations were carries out for additional electrodes to determine the capacity to weight ratio. These are listed in Table 17 which summarizes these and earlier calculations.

It would appear, based only on the above plot, that 4 micron plaque has some advantage over both 2 and 8 micron plaque and that 90% seems to be an optimum porosity.

Table 17 - Summary of Electrode Capacity Tests

Electrode ID	Thickness Nominal CM	Weight Grams	Avg.Capacity, Ah 26%KOH	31%KOH	Cap/Wt 31%KOH
A4-85-1-1	0.102	13.584	2.233	2.169	0.16
A4-85-1-2	0.102	13.711	2.227	2.161	0.16
A4-85-1-3	0.102	13.365	2.189	2.131	0.16
A4-85-3-1	0.102	12.567	2.256	2.194	0.17
A4-85-3-2	0.102	12.507	2.238	2.179	0.17
A4-85-3-3	0.102	12.457	2.242	2.177	0.17
A4-95-6-1	0.102	9.945	2.061	2.012	**0.20**
A4-95-6-3	0.102	10.276	2.123	2.076	**0.20**
A8-90-2-1	0.102	12.904	2.200	2.205	0.17
A8-90-2-2	0.102	12.821	2.183	2.189	0.17
A8-90-2-3	0.102	12.518	2.060	2.115	0.17
B2-90-2-1	0.152	21.527	2.941	3.029	0.14
B2-90-2-2	0.152	21.585	3.109	3.199	0.15
B2-90-2-3	0.152	21.014	3.006	3.106	0.15
B8-90-5-1	0.152	17.77	3.113	3.154	0.18
B8-90-5-2	0.152	18.421	3.183	3.220	0.17
B8-90-5-3	0.152	17.636	3.086	3.133	0.18
B8-90-6-1	0.152	18.967	3.298	3.298	0.17
B8-90-6-2	0.152	19.118	3.223	3.244	0.17
B8-90-6-3	0.152	18.373	3.183	3.202	0.17
I-6 Avg. 20C	0.0893	12.6		1.64	0.13

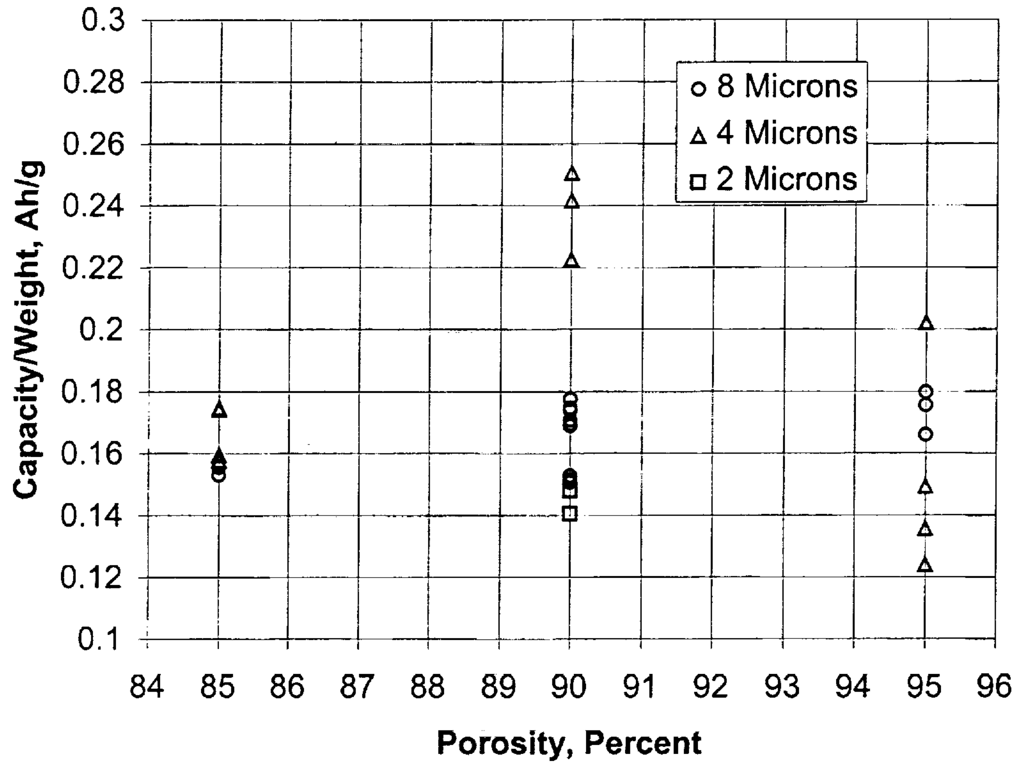
Calculations were carried out in July 1997 for additional electrodes to determine the capacity to weight ratio. These are listed in Table 18 below.

Table 18 - Summary of Electrode Capacity Tests

Previous EPI Impregnation Run Continued

Electrode ID	Thickness CM	Weight Grams	Avg.Capacity, Ah 26%KOH	31%KOH	Cap/Wt 31%KOH
C4-90-11-2	0.298	23.310	3.508	3.6305	0.16
C4-90-11-3	0.305	23.194	3.130	3.6015	0.16
C4-90-12-1	0.289	23.495	3.476	3.573	0.15
C4-90-12-3	0.322	23.350	3.541	3.641	0.16
C8-90-11-2	0.249	22.931	3.059	3.305	0.14
C8-90-12-3	0.262	21.780	3.558	3.2645	0.15
I-6 Avg. 20C	0.0893	12.6		1.64	0.13

Figure 1 - Electrode Capacity as a Function of Plaque Porosity



These electrodes were only of average performance, probably because they were relatively thick. Analysis of the graph presented in Figure 1 would have led one to expect better performance, discounting the effects of thickness.

Refurbishing of the available boiler plate cells was proceeding. These are 6 electrode-pair cells and were made to have a normal range of pressure during cycling. We had found some spare parts and ordered a few others.

One issue that had come up in connection with the boiler plate cells was the different capacities of the various test electrodes. Current distribution would undoubtedly not be uniform when connecting positive electrodes of different capacities in parallel in the same cell. Therefore, it would be necessary to build the cells with two + plates rather than six + plates. Because the cells are normally tested in series, differing cell capacities would require modification of the electrical setup. Capacity testing of electrodes impregnated at EPI continued into August 1997. Additional data are reported in Table 19.

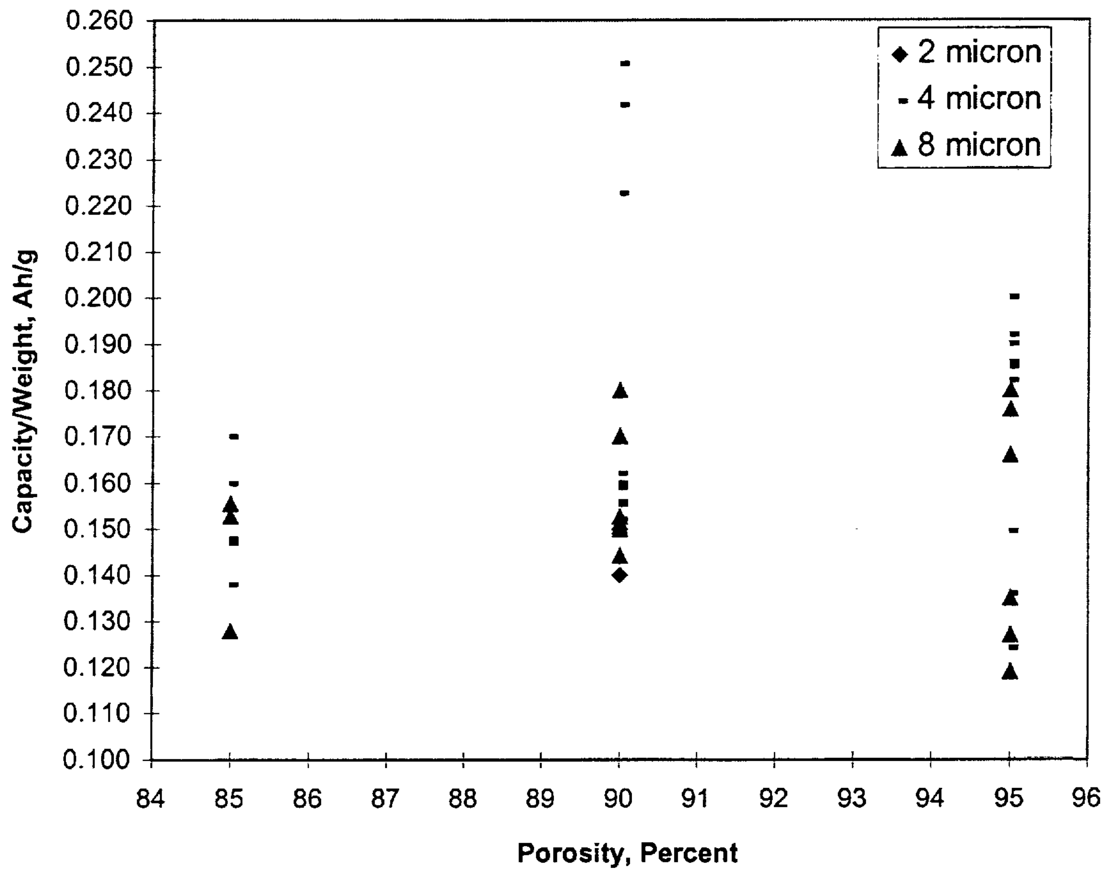
Table 19 - Summary of August Electrode Capacity Tests

EPI Impregnation Run #5 Continued

Electrode ID	Thickness CM	Weight Grams	Avg.Capacity, Ah 26%KOH	31%KOH	Cap/Wt 31%KOH
B4-95-5-1	0.184	12.329	2.23	2.3	**0.186**
C4-85-12-2	0.224	22.425	3.15	3.3	**0.147**
C4-85-13-2	0.250	23.867	3.39	3.5	**0.148**
C4-85-14-3	0.233	24.417	3.23	3.4	0.138
C4-90-13-3	0.264	21.352	3.36	3.5	**0.162**
C4-90-14-1	0.265	22.358	3.50	3.6	**0.160**
C4-90-14-3	0.267	22.167	3.44	3.5	**0.159**
C4-95-11-3	0.222	16.702	3.07	3.2	**0.192**
C4-95-12-1	0.216	16.745	2.98	3.2	**0.190**
C4-95-14-2	0.234	16.820	2.93	3.1	**0.185**
C4-95-14-3	0.244	17.769	3.06	3.2	**0.182**
A8-95-17-2	0.118	8.992	0.95	1.1	0.119
A8-95-18-1	0.107	8.780	1.08	1.2	0.135
A8-95-18-2	0.118	9.035	1.03	1.1	0.127
B8-85-11-1	0.185	14.212	1.74	1.8	0.128
I-6 Avg. 20C	*0.0893*	*12.6*		*1.64*	*0.13*

These electrodes were selected for test based on the curve presented in Report #189 as being more likely to have a relatively high capacity to weight ratio. The updated graph and the data are presented below in Figure 2. Although the thicknesses are not shown in the graph, the thickest electrodes (C) did not give as good performance as the two thinner (A and B) electrodes.

Figure 2 - Electrode Capacity as a Function of Porosity



The data in Table 20 is for capacity testing of electrodes impregnated at EPI during September 1997.

Table 20 - Summary of Electrode Capacity Tests

EPI Impregnation Run #5 Continued

Electrode ID	Thickness CM	Weight Grams	Avg. Capacity, Ah 26%KOH	31%KOH	Cap/Wt 31%KOH
B4-90-1-3	0.181	17.200	2.81	2.90	0.169
B4-90-2-1	0.158	16.199	2.62	2.70	0.167
B4-90-2-2	0.179	17.716	2.80	2.92	0.165
B4-90-2-3	0.160	16.740	2.68	2.76	0.165
B4-90-3-1	0.173	17.515	2.95	3.08	0.176
B4-90-3-2	0.202	18.220	3.02	3.12	0.171
B4-90-3-3	0.176	17.058	2.88	2.99	0.175
B4-90-4-1	0.164	16.524	2.78	2.92	0.177
B4-90-4-2	0.178	18.180	3.03	3.15	0.173
B4-90-4-3	0.188	17.618	2.99	3.12	0.177
B4-95-3-1	0.183	13.003	2.36	2.42	0.186
B4-95-4-2	0.220	13.499	2.23	2.29	0.170
B8-85-12-2	0.163	15.084	1.54	1.58	0.105
C8-95-1-1	0.171	12.671	1.59	1.68	0.133
C8-95-1-2	0.167	12.634	1.56	1.65	0.131
C8-95-2-2	0.182	11.710	1.29	1.36	0.116
I-6 Avg. 20C	0.0893	12.6		1.64	0.130

The electrodes presented in Table 21 below were selected for test as being more likely to have a relatively high capacity to weight ratio. The 4 micron 90% porosity electrodes gave the best consistent capacity to weight ratio considering the large spread with the 4 micron 95% data.

Table 21 - Summary of Electrode Capacity Tests

Electrode ID	Thickness CM	Weight Grams	Avg. Capacity, Ah 26%KOH	31%KOH	Cap/Wt 31%KOH
B4-90-5-2	0.186	**17.8**	3.000	3.160	**0.178**
B4-90-5-3	0.226	**16.3**	2.826	2.995	**0.184**
B4-90-6-1	0.226	**17.5**	2.997	3.181	**0.182**

There would appear to be no significant trend due to thickness according to the test data which was taken in the flooded state. Whether or not there would be a thickness effect in the starved state in a cell would have to be determined.

5. Boiler Plate Cells

Six boiler plate cells of 3.5 inch electrode diameter were built in November 1997. The cell capacities were matched as closely as the differing electrode configurations permitted. The details are given in Table 22 below. The cell capacity average was 12.85 Ah. The testing was based upon the lowest capacity cell, #1, 11.87 Ah, to avoid overstressing the lower capacity cells. For example, at 80% depth of discharge (DOD) for Cell #1, the equivalent DOD for the highest capacity cell, #3, 14.21 Ah, is 67%. The differing DODs complicated interpretation of the results. However this complication was not considered serious and enabled us to run the tests on one test set up in a reasonable length of time.

Of the six boiler plate cells which were built, four were satisfactory for testing. The other two had shorts which were too high resistance to blow but too low resistance to use as test articles. Two of the four cells had hard shorts which were blown with 50 - 100 amperes.

During the second cycle of 20 conditioning cycles, BP6 caused cycling to terminate due to a charge voltage over 2.0 volts; BP6 was removed from the test. It also showed a low capacity on subsequent discharge (0.90 Ah).

Conditioning capacities at the end of the 20 cycles were 9.4 Ah, 8.8 Ah, and 9.3 Ah for BP1, BP3, and BP5 respectively. BP3 had shown erratic capacities during cycling whereas BP1 and BP5 showed steady increases during cycling. Standard capacity tests would yield additional information on the health of these cells as would the dissassembly of BP6.

Table 22 - BP1, BP3, BP5, BP6 Rated for 26% KOH and 31% KOH

ID	Electrode wt, g	Rated Cap. Ah	26 % KOH Ave Ah	31 % KOH Ave Ah	---------------------------> Cap/Wt Ah/g	Total Cap Ah	Ave Cap/wt Ah/g
BP1							
B8-85-10-2	18.636	2.0	2.73	2.90	0.156	11.87	0.139
B8-85-10-3	17.417	2.0	2.53	2.71	0.155		
B8-85-11-1	14.212	2.0	1.74	1.82	0.128		
B8-85-12-2	15.084	2.0	1.54	1.58	0.105		
B8-85-14-2	18.681	2.0	2.69	2.86	0.153		
BP3							
C4-90-11-3	22.90	3.6	3.17	3.60	0.157	14.21	0.159
C4-90-12-1	23.00	3.6	3.49	3.57	0.155		
C4-90-13-3	21.352	3.6	3.36	3.45	0.162		
C4-90-14-1	22.358	3.6	3.50	3.58	0.160		
BP5							
B4-90-3-2	18.220	**3.0**	3.02	3.12	0.171	12.34	0.177
B4-90-4-1	16.524	**3.0**	2.78	2.92	0.177		
B4-90-4-3	17.618	**3.0**	2.99	3.12	0.177		
B4-90-6-1	17.500	**3.0**	3.00	3.18	0.182		
BP6							
A4-95-3-1	11.812	**2.0**	2.37	2.43	0.205	13.76	0.205
A4-95-3-2	11.928	**2.0**	2.49	2.50	0.209		
A4-95-3-3	11.252	**2.0**	2.35	2.33	0.207		
A4-95-4-1	11.745	**2.0**	2.42	2.42	0.206		
A4-95-6-1	9.945	**2.0**	2.07	2.01	0.202		
A4-95-6-3	10.276	**2.0**	2.13	2.08	0.202		

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13. ABSTRACT ***(Maximum 200 words)***

Samples of nickel fiber mat electrodes were investigated over a wide range of fiber diameters, electrode thickness, porosity and active material loading levels. Thickness' were 0.040, 0.060 and 0.080 inches for the plaque: fiber diameters were primarily 2, 4, and 8 μ and porosity was 85, 90, and 95%. Capacities of 3.5 in. diameter electrodes were determined in the flooded condition with both 26 and 31% potassium hydroxide solution. These capacity tests indicated that the highest capacities per unit weight were obtained at the 90% porosity level with a 4 μ diameter fiber plaque. It appeared that the thinner electrodes had somewhat better performance, consistent with sintered electrode history. Limited testing with two-positive-electrode boiler plate cells was also carried out. Considerable difficulty with constructing the cells was encountered with short circuits the major problem. Nevertheless, four cells were tested. The cell with 95% porosity electrodes failed during conditioning cycling due to high voltage during charge. Discharge showed that this cell had lost nearly all of its capacity. The other three cells after 20 conditioning cycles showed capacities consistent with the flooded capacities of the electrodes. Positive electrodes made from fiber substrates may well show a weight advantage of standard sintered electrodes, but need considerably more work to prove this statement. A major problem to be investigated is the lower strength of the substrate compared to standard sintered electrodes. Problems with welding of leads were significant and implications that the electrodes would expand more than sintered electrodes need to be investigated. Loading levels were lower than had been expected based on sintered electrode experiences and the lower loading led to lower capacity values. However, lower loading causes less expansion and contraction during cycling so that stress on the substrate is reduced.

14. SUBJECT TERMS
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